Labs

Lab Exams

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Much of biology laboratory teaching and testing is concerned with what Mary Calderone, in reference to sex education, likes to call "organ recitals." One of the primary, but unspoken, reasons for this is that it is easier to write and grade exams about nomenclature than to write good questions which test higher levels of understanding and insight, a difficult and time-consuming task. Prepared slides, preserved specimens, diagrams and models also lend themselves to questions about identification and nomenclature. Even though many teachers use living material in the lab, the prepared materials are usually what is left over for the exam and, consequently, what gets emphasized.

Why We Teach Biology

The reasons people become biology teachers vary greatly. Quite often an interest in the outdoors or some special group of organisms such as birds or reptiles motivates one to teach. With this interest, future teachers take a variety of basic courses in biology and education. The primary emphasis in university biology courses is usually language. Education courses stress the importance of learning the process of science. A thorough understanding of the principles of biology often does not develop until one has taught for several years. In many, it never develops because areas of interest are emphasized and the other material is covered out of a sense of obligation, often in the same way it was when the teacher was a university student.

Usually teachers depend heavily on a textbook and, if the text does not emphasize principles, they can be difficult to grasp. Many books that survey biology frequently include basic terminology to make them appear complete, and, consequently, they convey little understanding of principles. The result of all this is often a course which tests thinking processes and nomenclature but not principles.

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Why Do We Have to Learn This?

The question students ask: "Why do we have to learn this?", is very important. Unfortunately, it does not get enough attention because it is a most difficult question. Usually, it is answered by conceding that this is what always has been taught or is in the textbook, so biologists must think it is important. It is assumed that if you want to know something about biology you have to learn the terminology. And the final answer: it's going to be on the exam.

One often hears that the introductory course must introduce a certain amount of nomenclature to prepare students for later courses. What usually happens, however, is that teachers of these advanced courses discover that students do not understand the terminology very well. Often the students do not understand the principles very well either. Consequently, many teachers assume the students know very little when they start a new course.

As one teaches, learns and thinks about biology, one gains experience with what is important and what is not. Admittedly our experiences are not the same, but for general biology teachers there should be much common ground.

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Scientific Literacy

There has been much discussion recently about the failure of science instruction. The primary remedy currently being offered is to improve scientific literacy. For many science educators this means understanding scientific thought and its relation to ethics and societal problems. The use of discovery or inquiry to learn the principles of biology has been very effective. Emphasizing philosophy of science is a major content change.

Costenson and Lawson (*ABT* [1986] *48*:150-158) address some of these questions in their fine article about "Why Isn't Inquiry Used in More Classrooms?" They list 18 objectives for secondary science developed by the Arizona University Board of Regents. The objectives are concerned with understanding the nature of science, scientific investigation and communication. Most university professors would be delighted if their new graduate students possessed these skills. They also suggest that if lists of the major theories and postulates of biology are given to students at the appropriate time, we can reduce the need to cover large numbers of facts and help them focus on relevant ideas. To support their ideas, they point out the much higher achievement by BSCS students than traditional students.

But if BSCS students do so much better, why has the use of BSCS materials decreased rather than increased? The answer I most often hear to that question is that BSCS demands too much of high school biology teachers, i.e. many teachers do not feel they are adequately prepared to do all that

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BSCS requires. The fact that the authors of BSCS materials are aware of that problem is illustrated by the decrease in difficulty of subsequent editions of *Biological Science: Interaction of Experiments and Ideas,* a text which exemplifies the goals of Costenson and Lawson. One reason BSCS students do well must be that they have the best teachers.

I do not want to mislead you! There is no doubt in my mind that the BSCS materials are by far the best materials available for high school biology teaching. I became hooked on BSCS from the minute I heard Bentley Glass talk about it when I was a beginning university student. About that same time, I read Jerome Bruner's *The Process of Education*. I spent a summer in Washington, DC discussing the origin of ethics and values and ended up taking courses in the philosophy of science. No one could have been more interested in BSCS, inquiry based instruction, or the need to understand the nature and limits of science than I was when I began teaching.

I attended a NSF Preservice Academic Year Institute at Washington University in St. Louis the year before I began teaching. There I discussed the need for teaching about the nature and process of science with Barry Commoner. He saw no reason why beginning students needed to spend much time learning about the methods of science. As far as he was concerned, it was far more appropriate that these ideas be discussed after one had experience doing research. I was not pleased that he did not agree with me, but it did not take much teaching experience for me to realize that he was right.

I took a job teaching general science to 7th graders in an elite community because I couldn't find a good BSCS job. I was promised a biology position in a new multimillion dollar high school but was offered a position at a small college that emphasized laboratory instruction before construction on the high school began. I never got to teach BSCS but I tried adapting many BSCS experiments and ideas to my courses and I have had many students who have taken BSCS courses. I soon discovered that many of the BSCS lab exercises didn't work any better than many of the lab exercises I was finding in college lab manuals. And like many teachers, I discovered that good lab preparation takes lots of time. I also learned that teaching students the principles of biology was not easy.

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Explanation

The importance of good explanation is understood by everyone who wants to learn. When I took introductory biology at university I was fortunate enough to discover George Gaylord Simpson's *Life: An Introduction to Biology* and used it rather than the course textbook. For many years I taught using the late William Keeton's *Biological Science*. I have to confess that I learned the principles of biology by teaching from Keeton. His text integrated the principles of biology better than any text I have used. He brought an enthusiasm and a spirit of investigation to biology that made it enjoyable to learn. And he was a genius at explanation. Unfortunately, it has become more and more difficult for a single author to devote the time required to produce a textbook of this quality.

In the preface to the first edition, Keeton states a principle which I think is at the heart of all this discussion:

> It is my conviction that it is useless merely to mention a topic for the sake of 'completeness' of coverage, that if it is mentioned at all it should be given sufficient depth of treatment to make it meaningful. My experience in teaching the introductory biology course at Cornell (one taken by both science majors and students of the humanities) has shown me that it is often more difficult for a student to understand an oversimplified 'elementary' presentation than one that is rigorous enough to engender some insight into the relevance of the material.

The primary reason we teach biology ought to be that we believe there are biological principles and concepts that are meaningful and relevant to our lives. For me, biology raises the most meaningful and fascinating questions and it is, consequently, difficult for me to understand why there is so much interest in masquerading instruction in other forms of entertainment. When biology is included as part of another story, it often loses much of its vitality and discussion becomes limited. How do we convey this understanding and enthusiasm to our students? Hopefully, most people would agree that giving our students dictionaries of biology is no solution. It's nature itself and our ideas about it that give biology life.

The problem is time. Many argue that biology is so big it is now impossible to teach a general biology course. It's important to realize that this is not a new argument; it's a very old idea. Time is a problem because of the way lecture is used. For some reason, textbooks have become resource books and what's going to be on the exam has to be presented in lecture or written on a blackboard, overhead or handout.

Unfortunately, many of the important ideas of biology cannot be discussed in enough depth in lecture to develop understanding if all the major principles are to be covered. Even more significantly, many important insights about things biological can never be developed by reading textbooks or going to lectures—they need to be experienced.

My point is simple: we need textbooks that explain biological concepts in clear, interesting and meaningful ways. Biology is intrinsically interesting enough that our students should enjoy reading them. We may have to demand that they read the textbook, but they should feel it has been a rewarding experience. Classroom time should be spent helping the students understand the more difficult material, clarifying those areas where misconceptions occur, and giving students experience with living things.

For a number of years, I taught a full year of introductory university biology in the summer, in eight weeks. The class met five days a week, for three hours each morning. I told the students we were going to read Keeton from cover to cover. Lab and lecture were integrated. Students learned about stems by observing them in lab, not from drawings on the blackboard. I spent classtime making sure they understood concepts like osmotic pressure and expected them to learn most of the descriptive material from the text. Many of these students were not biology majors but were interested in taking a basic biology course so they could take the Medical School Admissions Test later that year. These students often came back to tell me how well they had done on the exam and thanked me for helping them learn so much biology quickly.

Many people are highly critical of textbook based instruction. The basis for this criticism is that the textbook becomes an authority and students get a unrealistic view of science as static rather than dynamic understanding of reality. That is not the fault of the textbook as an entity but rather what is in it. Keeton or BSCS certainly do not give that kind of view of science.

There is no doubt that discovery or inquiry based instruction works very effectively in teaching some concepts. Similarly, certain kinds of things are best learned by doing them. These ideas are not as new as some would like us to think. My teaching experience tells me that each concept being taught has to be thought about and the best method of teaching it determined. There is no single way of teaching everything; content and teaching method are very much interrelated. Fortunately, this is ideal since a course would be rather boring if everything were done in the same way.

Even though I expect students to learn about capillary circulation from the textbook, I know that they will not appreciate it until they have seen it, and they won't understand it until they understand osmotic pressure.

Before we can write examination questions we must have a very clear understanding of what it is we are trying to teach and why. The lack of widespread biological understanding may have more to do with the fact that many biology teachers do not have the training and experience necessary to appreciate the principles of biology. Under these circumstances, books that rely on oversimplified definitions to teach information rather than concepts may seem adequate to those teachers. Under these circumstances biological understanding will only increase in students when it has been developed in teachers.

Recently, there has been considerable interest in the misconceptions conveyed in biology instruction. This is an important area of research because it may help us focus on ways to improve instruction about certain concepts. Teachers are, of course, aware of many of these errors as they work with their students, but many misleading ideas have also crept into textbooks and we need to be made aware of these.

We also need help in focusing on the important ideas of biology. Perhaps we need lists of teaching objectives that focus on the most insightful aspects of concepts or areas of instruction rather than just listing content under terms like DNA, electron transport system or natural selection. The failure of biology education is never more apparent to me than when I hear people talk about DNA and then demonstrate they have little understanding of its significance when they begin to talk about nutrition. The number of people who are familiar with terms like Krebs cycle or glycolysis and, yet, have no understanding of the function of oxygen as the terminal acceptor in electron transport is saddening. The importance of recombination as a source of new phenotypes for natural selection rather than just mutation is poorly understood by many students of biology. If we can direct our teaching toward producing better understanding, we will improve biological literacy and thought. One of the most important ways we can do this is to develop better lab exams, but we can only do that if we have a clear understanding of why we teach what we do!

> *"One of the most important goals of biology education must be that we help students and citizens understand how little we know and how important it is that we understand fundamental processes."*

Even though I feel it is of utmost importance that we help our students learn how to think, I do not believe the purpose of biology is to teach the process of science. Rather, I feel, there is real danger in teaching that scientific thinking is the only way to think. We need to discuss the relevance of biological knowledge in dealing with overpopulation and all of the other problems man faces that have a biological component, but we must also realize that what we do about these problems involves areas outside the realm of science. This should emphasize the fact that we need to devote time and effort toward understanding ethical, religious and political values. Science and technology may create a safe morning-after pill, which will reduce much of the controversy about abortion, but it won't solve all our problems.

Before I end this part of the discussion I want to make my intentions clear. I have been critical of a variety of suggestions that have been made in an effort to improve biology teaching. Much of what has been suggested is of great value and will help us make progress toward improving scientific literacy, the goal we are all working toward. My purpose is to help bring focus on what I believe to be the primary problem biology teachers face: how to communicate and teach the principles of biology. My purpose is not to discourage others from working toward that goal.

Questions

From the preceding discussion one might get the impression I think there is a well defined set of principles of biology. Of course, that is not the case. *What we are trying to convey is understanding, not just information.* Questions contribute as much to understanding as answers. Even though I have said I don't feel the purpose of biology teaching is to teach "The" process of science, I do strongly feel that it is important that students think about how one answers the most fundamental questions. Thinking about these questions will require, and will improve, understanding of basic concepts. One of the most important goals of biology education must be that we help students and citizens understand how little we know and how important it is that we understand fundamental processes. Since intriguing questions motivate scientists to pursue basic research, our students should be stimulated by them as well.

Lab Exams

Despite the large numbers of laboratory manuals and publications about biology education, not much has been written about lab exams themselves. BSCS incorporates questions about lab experiences into its general examinations. Most other texts do this as well. Lab manuals contain information about preparing lab materials but little about how to test for understanding. Many assume that by answering questions in the manual that task has been accomplished.

Some research in science education argues that the goals of traditional labs can be met more efficiently by using other methods of instruction and that the only special function of laboratory is to teach the process of science. This brings us back to the basic question: why do we teach what we do. If the purpose of a lab is to learn the names of the organs of the digestive tract, it is likely that they can be learned in more efficient ways than dissecting a fetal pig. Hopefully, no one would argue that that is the sole purpose of such a lab. It is assumed that the qualities of the organs and their functional organization must be understood and appreciated before they can be identified on a practical exam. However, when students take shortcuts by memorizing diagrams in fetal pig manuals or names on a labeled specimen, these goals can be circumvented. I find it interesting that educators talk about multisensory learning but say little about multisensory testing.

Practical exams take a wide variety of forms, some of which even seem sadistic in the eyes of others. We've all heard stories about comparative anatomy professors who require students to identify bones by feeling them inside a bag rather than seeing them or teachers who set up the exam one station at a time, as the students enter the room, one at a time. Despite the variety, the important question is how well do the exams test for understanding of basic principles. If exams measure only the ability to remember information that can be learned from the text, they really are not lab exams. The best exams will test for understanding which is fundamental and intrinsic to comprehending the phenomena themselves.

The heart is a good example. Diagrams and textbooks can teach the chambers of the heart, pulmonary and systemic circulation, and a variety of other basic concepts. The response of the valves to pressure is easily understood outside the lab. However, until one sees a heart valve in action in a fresh heart and looks at its structure, one does not have much insight or understanding about its structure and function. How do we test for this understanding? The only way would be to ask about the functioning valve itself. Questions using a preserved heart get at some concepts but a fresh heart would be better. A functioning one would be even better. I've gotten around this problem by using photographs for lab exams. Usually I show slides of last week's lab and ask functional questions about the lab that can be answered only from experience. This sometimes presents problems because perspective is occasionally lost in photographs. I've also used photographs from textbooks, catalogs and other sources to try and ask about concepts on more traditional type practical exams. Individual oral exams where the student has to demonstrate understanding work very well but require too much time to be given often.

Ideally, short motion pictures of basic phenomena would be very useful in testing for understanding. Film loops and videotapes can be helpful but present practical problems in going from one example to another. The videodisc player may be an important solution to this problem. I'll talk about it next time.